Digital Photography with Flash and No-Flash Image Pairs

From Petschnigg 2004

You want to take a picture in a scene with low light. What do you do?

Solution	**Side effects**
Long exposure time	Motion blur
Open the aperture	Reduced depth of field
Increase gain	Increase in noise
Use flash	Unnatural lighting

flash

no flash

How can we combine the strengths of both?

Techniques:

- ambient image denoising
- flash to ambient detail transfer
- white balancing
- continuous flash adjustment
- red-eye correction

Pair Acquisition

1. Focus on the subject, then lock the focal length and aperture.
2. Set exposure time Δt and ISO for a good exposure.
3. Take the ambient image A.
4. Turn on the flash.
5. Adjust the exposure time Δt and ISO to the smallest settings that still expose the image well.
6. Take the flash image F.

Denoising

Bilateral filter

- Removes noise while still maintaining edges
- Just applied to noisy ambient image *A* (no use of flash image)

$$A_p^{Base} = \frac{1}{k(p)} \sum_{p' \in \Omega} g_d(p' - p)\, g_r(A_p - A_{p'})\, A_{p'}$$

normalization

weight based on spatial distance between pixels

sets the weight on the range based on intensity difference (edge-stopping)

Denoising

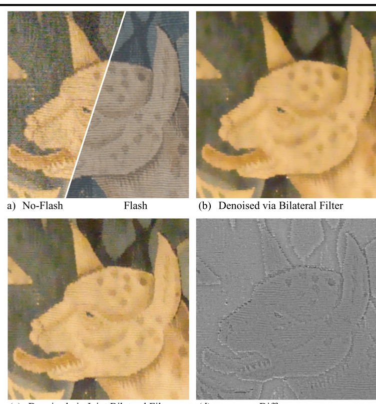
(a) No-Flash Flash (b) Denoised via Bilateral Filter

Denoising

Joint bilateral filter

- uses the flash image F instead of A to compute the edge-stopping function

$$A_p^{NR} = \frac{1}{k(p)} \sum_{p' \in \Omega} g_d(p' - p)\, g_r(F_p - F_{p'})\, A_{p'}$$



a) No-Flash Flash (b) Denoised via Bilateral Filter

(c) Denoised via Joint Bilateral Filter (d) Difference

Flash-To-Ambient Detail Transfer

- The joint bilateral filter can reduce noise, but cannot add detail that may be present in the flash image.

Flash-To-Ambient Detail Transfer

So, we compute a detail layer:

$$F^{Detail} = \frac{F + \varepsilon}{F^{Base} + \varepsilon},$$

F^{Base} is computed using the basic bilateral filter on F.

And apply it to the denoised ambient image:

$$A^{Final} = (1 - M) A^{NR} F^{Detail} + M A^{Base}$$

Flash-To-Ambient Detail Transfer

(c) Denoised via Joint Bilateral Filter (e) Detail Layer (f) Detail Transfer

Flash-To-Ambient Detail Transfer

No-Flash | Detail Transfer with Denoising | Long Exposure Reference

Detecting Flash Shadows and Specularities

Orig. (top) Detail Transfer (bottom) Detail Transfer without Mask

Detecting Flash Shadows and Specularities

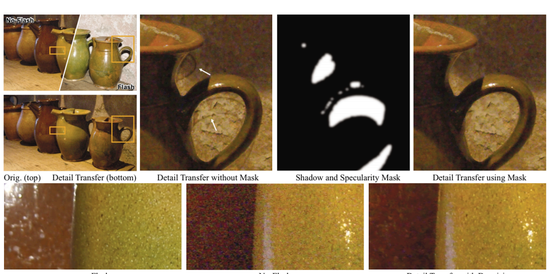
To solve this problem, we use a threshold-based shadow mask:

$$M^{Shad} = \begin{cases} 1 \text{ when } F^{Lin} - A^{Lin} \leq \tau_{Shad} \\ 0 \text{ else} \end{cases}$$

We also want to detect specular regions caused by the flash. To do this, we just look for luminance values in the flash image that are greater than 95% of the range of sensor output values.

Then, we merge the two masks and feather the edges.

Detecting Flash Shadows and Specularities



Orig. (top) Detail Transfer (bottom) | Detail Transfer without Mask | Shadow and Specularity Mask | Detail Transfer using Mask

Flash | No-Flash | Detail Transfer with Denoising

White Balancing

- Think of the flash as adding a point light source of known color to the scene
- Illumination due to the flash only: $\Delta = F^{Lin} - A^{Lin}$
- Estimate the ambient illumination at the surface with the ratio:

$$C_p = \frac{\Delta_p}{A_p}$$

- Analyze this at all image pixels to infer the ambient illumination color *c*.

White Balancing

White-balance the image by scaling each color channels as:

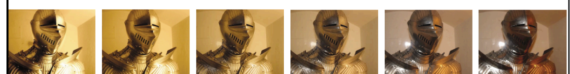
$$A_p^{WB} = \frac{1}{c} A_p$$

Original No-Flash   Estimated ambient illumination   White-Balanced

Continuous Flash Adjustment

- Convert Flash and Ambient images to YCbCr space and interpolate linearly:

$$F^{Adjusted} = (1-\alpha)A + (\alpha)F$$



-0.5   0.0 (No-Flash)   0.33   0.66   1.0 (Flash)   1.5

Figure 10: An example of continuous flash adjustment. We can extrapolate beyond the original flash/no-flash pair.

Red-Eye Correction

- Convert the pair to YCbCr space (decorrelates luminance from chrominance)
- Compute a relative redness measure:

$$R = F_{Cr} - A_{Cr}$$

- Segment the image into regions where $R > \tau_{Eye}$
- Look for seed pixels where

$$R > \max[0.6, \mu_R + 3\sigma_R] \text{ and } A_Y < \tau_{Dark}$$

Red-Eye Correction

No-Flash   Flash   Red-Eye Corrected

Red-Eye Correction

Closeup with Faint Red-Eye

No-Flash   Flash   Red-Eye Corrected

Summary

Techniques:

- ambient image denoising
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